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A Twenty - Year Report
On The Illinois
Continuously Reinforced Pavement

State of Illinois
DEPARTMENT OF PUBLIC WORKS AND BUILDINGS
Division of Highways
Bureau of Research and Development

A TWENTY-YEAR REPORT ON THE
ILLINOIS CONTINUOUSLY REINFORCED PAVEMENT

By

John E. Burke, Engineer of Research and Development, and

Jagat S. Dhamrait, Principal Research Engineer

A Research Study

By

Illinois Division of Highways
In Cooperation with
U.S. Department of Transportation
Federal Highway Administration
Bureau of Public Roads

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The possibility that continuous reinforcement could serve in portland

cement concrete pavements as a means for eliminating or greatly reducing

the numbers of transverse joints and open cracks that too often have become

points of weakness in otherwise sound pavements was suggested many years

ago. Continuous reinforcement was used as early as 1921 in the Columbia

Pike experimental pavement near Washington, D. C. The next recorded use

was in an experimental pavement built on Route US 40 in Indiana west of

Indianapolis in 1938.

With this background of the principal experience to draw upon, the

Illinois Division of Highways in cooperation with the U. S. Bureau of

Public Roads in 1946 undertook an experimental study to develop more

definite information on the relationships between performance and slab

dimensions and steel amounts of continuously reinforced pavements. The

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establishment of the project in Illinois was generated largely through the efforts of W. R. Wooley of the Bureau of Public Roads and J. D. Lindsay of the Illinois Division of Highways.

The Illinois study has been centered on an experimental continuously reinforced pavement constructed in 1947 and 1948 on Route US 40 west of Vandalia. The study was first described by H. W. Russell and J. D. Lindsay in a report entitled "An Experimental Continuously Reinforced Concrete Pavement in Illinois," published in the Highway Research Board Proceedings of 1947. A second report by Russell and Lindsay, entitled "Three-Year Performance Report on Experimental Continuously Reinforced Concrete Pavement in Illinois," was published in the Highway Research Board Proceedings of 1951. A third report by Lindsay entitled "A Ten-Year Report on the Illinois Continuously Reinforced Pavement," was published in 1959 in Highway Research Board Bulletin 214. The current report which covers a 20-year span of service of the pavement is intended to be the final report of the study. While most of the experimental pavement is structurally capable of continuing to serve the heavy traffic now being served, the construction of paralleling pavements on the Interstate system soon (1967) will divert all but local traffic from the experimental pavement.

Only the most important information concerning the design, construction and early research observations is presented in the present report. Readers wishing further detail are referred to the previous reports.

Construction of the Illinois experimental pavement began on September 25, 1947 and was completed on May 20, 1948. It was opened to traffic immediately upon completion.

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The experimental section of continuously reinforced pavement is 5 1/2 miles long and divided into eight test sections, six of which are about 3,500 feet long and two of which are about 4,200 feet long. The pavement is 22 feet wide, and placed directly on natural fine-grained soil. The longitudinal reinforcement is continuous through each test section but not between sections. It consists of round deformed bars (ASTM 305-47T) meeting the requirements of ASTM designation A 16 for rail-steel bars. Transverse reinforcement consists of round deformed bars meeting the ASTM designation A 15 for intermediate grade billet steel, chosen to permit welding of supporting steel to the bars. The transverse bars extend through the entire width of the pavement and the customary center joint has been omitted. Various details of the test sections, including the size and spacing of the steel reinforcement, are presented in Table 1. The results of mill tests of the reinforcing steel are presented in Table 2.

Table 1

Table 2

Four of the test sections are uniformly 7 inches thick and four are 8 inches in thickness. Four percentages of longitudinal steel, 0.3, 0.5, 0.7, and 1.0 percent, based on the gross cross-sectional area of the pavement, were used with each thickness of pavement. Both bar size and spacing were varied to obtain the different percentages of steel. The reinforcement bars were assembled as a continuous mat on the subgrade by means of chairs extending upward to approximately 3 inches below the finished surface of the pavement. Splice laps were maintained at a length equivalent to 30' bar diameters. Air-entrained concrete was deposited to full pavement thickness in a single operation and finished by means of a conventional spreader and finishing machine followed by the usual hand operations.

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A conventional concrete pavement constructed immediately west of the experimental pavement at about the same time and carrying approximately the same traffic has been used as a control section. This pavement was built to the Illinois standard design of the period and consists of a 10-inch slab reinforced with welded wire fabric at the rate of 78 lb. per 100 sq. ft., with doweled contraction joints spaced at 100-foot intervals and no expansion joints. Unlike the continuously reinforced pavement which was placed directly on the natural fine-grained soil, the conventional pavement was placed on a 6-inch thickness of granular subbase.

The continuously reinforced pavement has been the subject of many observations and measurements from the time of its construction, and a relatively thorough record of its performance has been obtained. Certain pertinent observations and measurements have also been made on the adjoining conventional pavement.

Both the continuously reinforced pavement and the adjoining conventional pavement have carried practically the same traffic (two-way) since construction. The reader is referred to Table 6, which appears in a following section of the report, for summary information on traffic volumes. Traffic conditions are discussed more fully in this later section.

TRANSVERSE CRACKING

Characteristic of continuously reinforced pavement are stress-relieving transverse cracks that develop at very close intervals. Crack development begins shortly after placement of the concrete as shrinkage takes place during setting and drying. It is an essential feature in the design of continuously reinforced pavement that the longitudinal steel reinforcement

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be properly distributed and of sufficient area to maintain the structural

integrity of the slab by preventing the cracks from opening excessively

during contraction of the concrete.

The crack frequencies near the free ends of long continuously rein-

forced slabs would be expected to be similar to those in conventionally

reinforced slabs. This proved to be the case in the Illinois experiment

and has been described in the earlier reports. The crack frequency was

found to increase gradually away from the ends up to a distance of about

500 feet, to decrease over the next few hundred feet, then to become

fairly stable through the longer center portion of the pavement. This

is demonstrated in Figure 1 which appears also in an earlier report.   Figure 1

Two relationships are of special significance in the consideration

of transverse cracking of continuously reinforced pavements. One of these

is that which exists between crack frequency and age; the other is the

relationship between crack frequency and steel percentage. Both are shown

in Figures 2 and 3 for the Illinois experimental pavement for the 20-year   Figure 2
                                                                                   Figure 3
period that it has been under observation. Figure 2 is concerned with

average crack interval in each of the sections of 7-inch pavement of vary-

ing steel percentage; Figure 3 is concerned with the same information for

the 8-inch pavement sections.

With regard to the crack frequency and age relationship, it will be

seen in Figures 2 and 3 that the average crack interval decreased rather

rapidly during the first three or four years following construction, after

which the rate of decrease became and stayed very slow through the remainder

of the 20 years of observation. It will be noted also that the rate of

decrease has been slowest for the higher steel percentages.

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A definite relationship between crack frequency and steel content is also obvious from an inspection of Figures 2 and 3. It will be noted that at all ages at which observations of crack frequency have been made up to 20 years, the average crack interval is consistently lower for each incremental increase in steel percentage. This relationship is in accord with theory regarding the behavior of long continuously reinforced slabs subjected to temperature and moisture changes.

The magnitude of the average crack intervals and of the changes in the average intervals that have taken place through the years are of interest. Referring again to Figures 2 and 3, it will be seen that, with the exception of the 0.3 percent steel sections which have proven to be inadequate, average crack intervals ranged from about 5 to 9 feet at the end of 4 years and from about 5 to 8 feet at the end of 20 years.

TRANSVERSE CRACK WIDTH

It is essential that the steel reinforcement of continuously reinforced pavements hold the cracks to a narrow width if these pavements are to function properly. Open cracks can be expected to destroy the continuity afforded by aggregate interlock, a continuity that is needed to prevent excessive flexing under traffic with resultant spalling of the concrete and rupture of the steel. Excessive openings can lead also to the infiltration of incompressible material, causing spalling and blowups; and to the entrance of water to reduce subgrade support and cause rusting of the steel. Failures that have taken place at some of the construction joints on the experimental project give ample evidence of the importance of aggregate interlock and the need for narrow crack openings.

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Transverse crack openings in continuously reinforced pavements have been found to be not the same width for the entire thickness of the pavement and are difficult to measure. The apparent width observed by looking at the surface of the pavement is characteristically greater than the width through most of the depth of the crack.

Early in the study 60 transverse cracks were selected from each test section for periodic measurements of crack width with a measuring microscope capable of measuring to 0.001 inch. Ten cracks were selected to represent the cracks at each end of each test section, another ten to represent those at each quarter point, and 20 to represent those at the center of each section. The first crack width readings were made in July 1948.

In an attempt to obtain width readings most nearly representative of the true width of the cracks, the microscope was focused some distance down the crack. While the method is not considered to be extremely accurate it is believed to have given fairly reliable results, although the widths may be somewhere in between those visible at the surface and the actual widths through the major portion of the pavement depth.

Average crack width data for the transverse cracks measured in each section are shown in Figure 4 for the 7-inch sections and in Figure 5 for the 8-inch sections for the years 1948, 1957, and 1967. Averages are for 60 cracks measured in each section, except for the 1967 measurements in which some patching and resurfacing removed a few cracks in the 0.3 percent steel sections from the observation.

Figure 4
Figure 5

It will be noted from Figures 4 and 5 that a correlation has existed between crack width and the percentage of longitudinal steel through 20

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years of observation of the experimental pavement. Crack widths become progressively smaller as the percent of steel increases. It is also apparent that crack openings have become wider with time. The rate of increase, however, seems to have decreased with time.

The 7-inch sections, except for the 1.0 percent steel section, in 1948 showed somewhat wider crack openings than did the 8-inch sections. In 1967 this trend had become reversed. No explanation for these observed conditions is apparent.

The pavement surface at most of the cracks now shows occasional slight spalling. The amount and severity of the spall is related to the percentage of longitudinal reinforcement, and is most pronounced in the sections having 0.3 percent of steel. Little increase in spall has taken place after the first few years, and that which is visible after 20 years of service does not detract appreciably from the general appearance of the pavement, nor require any maintenance. The cracks are not visible to occupants of vehicles traveling the pavement at ordinary speeds. Photographs of a typical transverse crack in each of the sections of 7-inch pavement taken in 1950, 1957, and 1967 are shown in Figure 6.

Figure 6

. Except at a few cracks in the 0.3 percent longitudinal steel sections where excessive movement and obvious failure have taken place, the performance of the pavement at transverse cracks of all sections must be considered to be satisfactory. The structural continuity of the pavement has been maintained. While the crack openings are such that evidence of the infiltration of very fine material that might be speculated to have been moisture-deposited has been found, no signs of serious structural damage attributable to this source have been observed.

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Photographs of cores taken through typical transverse cracks in the

7-inch sections in 1967 are shown in Figure 7. It is apparent in the   Figure 7

photographs that the crack openings become very fine a short distance

below the surface, at about the level of the steel reinforcement, and

remain fine to the bottom of the pavement. An examination of the cores

showed a discoloration of the slab faces at the cracks, indicative of

the infiltration of fine material. An examination of the condition of

the steel reinforcement in the cores showed only a negligible amount of

rusting.

The need to remove a portion of the experimental pavement in 1965

as part of a new construction contract provided an opportunity to observe

closely the condition of the steel of a continuously reinforced pavement

after 18 years of service. The new construction required the removal of

957 lineal feet of Section 7, which is the 8-inch pavement with 1.0 percent

of longitudinal steel.

The pavement of Section 7 was considered to be in excellent condition

at the time of removal. Transverse cracks appeared to be tight and showed

only a minor amount of spalling at the edges. The longitudinal cracks

that had formed through most of the section in the absence of a con-

structed center joint were somewhat wider than the transverse joints and

showed somewhat more spalling.

Removal of the concrete confirmed previous observations that transverse

cracks assume hair-like widths below the surface of the pavement. It was

evident, too, that a thin layer of soil accumulates in most cracks.

Very slight rusting was found commonly to occur on the surface of the

steel at transverse cracks. The rust stains imprinted on removed concrete

appeared generally to progress no more than from one to three inches beyond

the cracks. Beyond this point, no rust stain was evident. Observations of

the condition of the steel deformation imprints in the concrete showed no

evidence of slip between steel and concrete. No evidence of slippage was

found in lap areas. The degree of rusting of the longitudinal steel at

the transverse cracks was considered to be minor. Typical conditions

of bars removed at transverse cracks are shown in the photograph of

Figure 8.   Figure 8

LONGITUDINAL CRACKS

As stated previously, the conventional center joint was omitted from

the Illinois experimental continuously reinforced pavement. The No. 3

round deformed bars that were used as transverse reinforcement were extended

across the entire width of the pavement spaced at 12-inch centers in half

of each test section and at 18-inch centers in the other half.

Longitudinal cracks began to form in some of the test sections soon

after construction and now involve most of the experimental pavement. Most

of the longitudinal cracking does not coincide with the center of the pave-

ment; however, it rarely meanders more than three feet away from the center.

In a few instances two parallel longitudinal cracks are present; more rarely,

there are three present.

Previous reports have described a relationship that appeared to exist

between the time of year of construction and the extent of longitudinal

cracking. The pavement constructed during the fall of 1947 showed a much

earlier development of longitudinal cracking than did that constructed in

the spring of 1948. As will be seen from Table 3, this relationship was   Table 3

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still apparent at the end of ten years. At the end of 20 years, longitudinal cracking has progressed to the extent that the relationship becomes less distinct. No explanation can be offered for the slower development of longitudinal cracks in the spring construction. No other consistent relationships between longitudinal cracking and the variables under consideration, including the two spacings of transverse steel, have been observable.

A considerable amount of surface spall is visible at some of the longitudinal cracks, and the cracks have the general appearance of being open wider than most of the transverse cracks.

In the removal of pavement from Section 7 mentioned previously, the concrete was found to have been less protective of the steel, both transverse and longitudinal, at the longitudinal cracks. Transverse bars were often found to be quite severely rusted and sometimes broken at the longitudinal cracks. A "necking down" of the bars and an accompanying fracture in the form of a cup and cone noted in many instances indicate the possibility of tensile deformation before fracture. The stage of rusting of the fracture faces indicated in many instances that the steel had been broken for some time. Longitudinal bars exposed by the formation of longitudinal cracks also showed some rusting. An example appears in the photograph of Figure 9.

Figure 9

The concrete that was removed was found to be of good quality and uniformly well consolidated around the steel. No durability defects were evident.

Experience with the formation of longitudinal cracks and the subsequent behavior of the pavement at these cracks in the Illinois experimental continuously reinforced pavement constructed without a center joint indicates

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that the center joint used in conventional pavement should be used also in continuously reinforced pavement.

PAVEMENT PUMPING

When the Illinois experimental continuously reinforced pavement was being planned over 20 years ago, it was believed that the absence of joints at closely spaced intervals, the tightness of the cracks, and an inherent flexibility which would allow the pavement to adjust to minor subgrade movement would be sufficient to control pumping of fine-grained soils and eliminate the need for a granular subbase. This was of special interest in reducing the total cost of construction. The pavement was constructed therefore on the natural fine-grained subgrade to test this belief. Most of the subgrade soils of the project are of the A-7-4, A-4, A-4-2, and A-6 groups, all known to be capable of pumping under the rainfall conditions (about 38 inches average annual precipitation) that exist at the location of the experimental project. The anticipated volume of heavy truck traffic is sufficient to produce pumping of conventional pavements.

At the time of preparation of the ten-year report, serious pumping had been noted at the expansion joints that were placed between the experimental sections, and at most of the construction joints placed at the end of each day's run in the sections with 0.3 and 0.5 percents of steel. The construction joints in sections with 0.7 and 1.0 percents of steel showed neither pumping nor faulting. The pumping, where found, was associated with considerable pavement distress that made patching necessary. Pumping also has been excessive at wide transverse cracks in the low-steel-content sections where the longitudinal reinforcement obviously had fractured.

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A small amount of edge pumping not associated with joints or open transverse cracks has been observed on the 0.3 and 0.5 percent steel sections. No pavement failures have been observed that can be attributed to this pumping.

The expansion joints were installed in the pavement as part of the experimentation to assure that each test section would act independently. This usage would not be a part of normal construction of continuously reinforced pavement. However, the inherent weakness that is present at unprotected slab ends needs to be recognized when designing terminal systems at such locations as bridges and the ends of construction projects.

Construction work was terminated each day by the placing of a wood header. When concrete placement was resumed, the header was removed and the new concrete placed against the older concrete. No longitudinal reinforcement in addition to that of the normal design of the section was placed at these joints.

Pumping that was visible at construction joints in the 0.3 and 0.5 percent reinforcement sections at the time of the ten-year survey (at all construction joints in the 0.3 percent steel sections and two of seven in the 0.5 percent steel sections) has led subsequently to failure of the pavement at most of these locations, making patching necessary. The joints in the 0.7 and 1.0 percent reinforcement sections are still in good condition after 20 years of service.

The behavior of the pavement at the construction joints of the Illinois experimental pavement is interpreted to indicate a need for additional reinforcement at construction joints if performance equal to that away from the joints is to be achieved.

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It has long been known that even slight pumping is likely to progress to a severe stage, and cannot be depended upon to remain slight through the ordinary life of a pavement. Although pumping of serious consequence has been confined principally to joints and open cracks in the sections in which the steel content might be considered inadequate, it would appear prudent to include a protective subbase with continuously reinforced pavement where the use of a subbase would seem warranted with conventional pavement.

CHANGE IN LENGTH

The four-inch expansion joints that were installed between test sections allowed each considerable freedom to change length. In the early years following construction, seasonal movements of one to two inches between summer and winter, with the sections being larger in the summer, were recorded. By the summer of 1957 all of the joints that were four inches wide when constructed were tightly closed. Large spalls indicative of excessive compression were observable at several of the joints and major repairs were required. Subsequently, patching has been required at almost all of these joints.

The cause of the growth of the pavement cannot be stated with certainty. Growth of the concrete itself cannot be excluded entirely as a possibility. However, some readings taken in 1957 between gage plugs which were not influenced by transverse cracks did not show much variation from initial readings, giving indication that growth of the concrete was not a major factor. The most logical explanation of the growth seems to be an incomplete closure of transverse cracks once they form. The finding of slight coatings of soil in crack openings supports this explanation.

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The experience gained on this research project, where expansion joints
were placed at 3,500 to 4,200-foot intervals, has not been sufficient to
allow prediction of the behavior of larger runs, or of the requirements
for expansion space. Nor can predictions be made of the amount of restraint
that would be required to prevent growth of the pavement. Theoretical con-
siderations suggest that considerable restraint is already present.

STRESSES IN LONGITUDINAL STEEL

For successful performance of continuously reinforced pavements,
stresses in the steel must remain below the yield point; otherwise, the
cracks would become excessively wide.

During the construction of the Illinois experimental pavement, SR-4
strain gages were mounted on selected longitudinal bars in the 7-inch and
8-inch sections containing 0.7 percent of steel. Many stress readings
were taken during the first month following construction, and periodically
but less frequently thereafter.

In the fall 1947 construction, a maximum average stress of 62,400 psi
was measured at a preformed transverse crack in January 1948. This is within
a critical range of the 70,000 psi yield point of the rail steel bars of the
section. Stresses away from the crack never measured higher than 10,000 psi.
In the spring 1948 construction, a maximum average stress of 42,000 psi was
recorded the following January.

The strain gages became inoperable in a relatively short period of
time and did not yield usable data beyond one season of contraction. During
their period of operation, the gages showed that the tensile stress of the
steel bears an inverse relationship to slab temperature, being high when

the temperature is low and low when the temperature is high. The stress

in the steel was seen to respond rapidly to daily changes in temperature,

and to show considerable variation in a 24-hour period.

The strain gage study is reported in more detail in earlier reports,

particularly in the three-year performance report.

RIDING QUALITY

The Illinois experimental continuously reinforced pavement was judged

from the beginning by Illinois Division of Highways' engineers to offer

better-than-average riding quality. As the years passed, it was agreed

generally that the pavement was retaining this characteristic. Roughness

measurements that were begun in 1957 when the Division of Highways acquired

a Bureau of Public Roads' type roughometer have confirmed the earlier judg-

ments.

The results of roughometer measurements made in 1957, and again in

1962, 1964, and 1967, are presented in Table 4. Each value of the Roughness   Table 4

Index that is shown is the average for measurements made in each of the four

wheelpaths of the two-lane pavement. It will be noted that, with the excep-

tion of the Roughness Index reading of 92 that was recorded for Section 1

(7-inch thick, 0.3 percent steel) in 1967, all readings, including those

for the conventional pavement, indicate riding surfaces in the "smooth"

and "very smooth" categories. It will be noted also that, with the excep-

tion of Section 1, little change in riding quality has taken place during

the ten years that roughometer measurements have been made. Most of the

experimental sections have been, and have remained, somewhat smoother than

the conventional pavement.

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PERFORMANCE

Carey and Irick, in a paper entitled "The Pavement Serviceability Performance Concept," that appeared in Highway Research Board Bulletin 250, describe a system for estimating pavement ratings of serviceability and for determining performance by summarizing the serviceability record over a period of time. The system, for concrete pavements, involves measurements of riding quality, cracking, and patching.

Under the serviceability performance concept, the term "present serviceability" was chosen to represent how well a pavement is serving high-volume, high-speed, mixed truck and passenger vehicle traffic at a specific time. A mathematical index (Present Serviceability Index) was developed for estimating subjective ratings of present serviceability through objective measurements taken on the pavement. The relationship, modified to make use of the Roughness Index as provided by the Illinois roughometer, can be expressed as follows:

$$P = 12.0 - 4.27 \log \overline{RI} - 0.09 \sqrt{C + P}$$

where

P = Present Serviceability Index

$\overline{RI}$ = Roughness Index in inches per mile as obtained by the Illinois roughometer

C = cracking in lineal feet per 1000 square feet of pavement area, considering only those cracks that are open or spalled at the surface to a width of 1/4 inch or more for at least half the crack length; also sealed cracks.

P = bituminous patching in square feet per 1000 square feet of pavement area.

Under the present serviceability concept, the present serviceability rating is expressed on a scale between 0 and 5 as follows:

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5
    Very good
4
    Good
3
    Fair
2
    Poor
1
    Very poor
0
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Illinois highway engineers consider a Present Serviceability Index of 2.0 or lower to indicate a need for reconstruction or replacement of a two-lane pavement on the primary system.

The results of measurements that were made in 1962, 1964, and 1967 to compute the Present Serviceability Indexes (PSI's) of the experimental pavements, and the computed Present Serviceability Indexes, are presented in Table 5. The computations and the Present Serviceability Indexes for the conventional pavement also are presented.

Table 5

It will be noted in the table that during the past ~~ten~~ *five* years all of the experimental sections with the exception of Section 1 (0.3 percent steel), and also the conventional pavement, have rated as "Good" or "Very Good" under the present serviceability concept. Section 1 has rated as "Fair." It will be noted that a fairly consistent relationship exists between steel content and Present Serviceability Index, with pavements of higher steel content showing higher Present Serviceability Indexes. The relationship between pavement thickness and Present Serviceability Index is less consistent.

With the possible exception of the 7-inch section having 0.3 percent steel content, all experimental sections and the conventional pavement

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used as a control are continuing to offer satisfactory service 20 years

after construction. Some of the experimental pavements may be providing

slightly better service than the conventional pavement; some appear to be

providing a slightly lesser degree of service. In general, the sections

of greater steel content and greater thickness are providing the better

service.

It will be recalled that the conventional pavement was placed on

granular subbase while the experimental continuously reinforced pave-

ments were placed on the natural fine-grained soil subgrade. It is also

to be remembered that the principal failures in the continuously rein-

forced pavements took place at expansion joints installed only because

of the experimental nature of the project, and at construction joints

where the weakness undoubtedly can be overcome through the use of addi-

tional steel.

TRAFFIC

The traffic that the experimental pavements have carried through

the years is typical in volume and character of the traffic on many

primary highways serving a high percentage of through truck traffic.

Average daily traffic volumes for representative years, based on manual

and machine counts, and shown separately for passenger cars, single-

unit trucks, and multiple-unit trucks, are presented in Table 6.   Table 6

To evaluate the performance of a pavement in relation to the axle

loadings to which it has been subjected, it is convenient to represent

the varying axle loadings which a pavement receives to a single loading

having the same effect on the pavement structure. The AASHO performance

equations are often used to accomplish this purpose.

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Engineers of the Illinois Division of Highways and others have made use of loadometer data and traffic volume count and classification data in conjunction with the AASHO Road Test performance equations to estimate equivalent numbers of a standard axle loading to represent mixed loadings applied to pavements. Usually, the equivalency is established on the basis of an 18,000-lb. single-axle loading. The system that is being used in Illinois was reported by W. E. Chastain, Sr., in a paper entitled "Application of Road Test Formulas in Structural Design of Pavement," which appears in Highway Research Board Special Report 73.

Equivalent 18,000-lb. single-axle loadings have been computed by Illinois procedures to represent cumulative mixed loadings applied to the experimental pavements beginning with the opening of the pavement to traffic. The results of these computations are shown graphically in Figure 10.

Figure 10

SUMMARY OF PRINCIPAL FINDINGS

Observation of the behavior of the Illinois experimental continuously reinforced pavement and an adjacent conventional control pavement over a 20-year service period indicates the following:

(1) Transverse cracks begin to develop at closely spaced intervals in continuously reinforced concrete pavements soon after construction. The number of cracks increases with age, but at a very slow rate after the first few years. Crack frequency increases with the amount of longitudinal steel.

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(2) For the sections under study, no strong differences occurred between the behavior of the 7-inch and 8-inch thicknesses of pavements.

(3) Crack width is an important factor in the behavior of continuously reinforced pavements. Narrow cracks are essential to the maintenance of structural integrity of the pavement system. Crack width is a function of steel content, with lesser width being associated with higher steel content. Crack width increases slowly with age.

(4) Slight spall begins to occur at transverse cracks in continuously reinforced pavement soon after construction. The spall increases with age and is related in amount inversely to the amount of longitudinal steel. Within the 20 years of service of the experimental pavements, spall at transverse cracks has not become a defect requiring maintenance.

(5) Meandering longitudinal cracks will occur in a continuously reinforced pavement constructed greater than one-lane width without a center joint. Within the transverse steel contents investigated (No. 3 bars at 12-inch and 18-inch centers), the longitudinal cracks can become unsightly and a source of structural weakness within the expected life of a pavement.

(6) Construction joints are potential sources of weakness at longitudinal steel contents of less than 0.7 percent.

(7) When longitudinal movement is unrestrained, seasonal movements of continuously reinforced pavements can be expected, and also

permanent increases in length with age. The cause of the growth

was not apparent from examination of the existing experimental

pavements.

(8) Continuously reinforced pavements can be designed and con-
structed to serve at least as effectively as conventional pave-
ments, and have the potential of overcoming the basic weakness
that occurs at transverse joints of conventional pavements.

(9) Continuously reinforced pavements can be built to, and can retain
for long periods of time (at least 20 years), a high standard of
surface smoothness.

(10) While pumping has not been a major cause of failure of the experi-
mental continuously reinforced pavement during 20 years of ser-
vice, it has nevertheless been sufficient in amount to indicate
that continuous reinforcement is not a positive protection against
pumping.

DESIGN RECOMMENDATIONS

Considering the traffic loadings to which the experimental continuously

reinforced pavement has been subjected (equivalent to single-axle loadings

of 18,000 lbs.), it would appear that:

(1) A 7-inch thickness of pavement will probably be adequate. However,
unless future loadings can be predicted with a fair degree of
certainty, conservatism would suggest an 8-inch thickness.

(2) The selection of the amount of longitudinal steel requires con-
siderable judgment. The general appearance of the 0.3 percent

longitudinal steel sections after 20 years suggests that satis-
factory performance through many more years cannot be expected.
The 0.5 percent steel sections are still performing well, and
this steel content can be considered a minimum. The 0.7 percent
steel sections have a generally better overall appearance
(slightly less spall at transverse cracks), but to date can be
said not to be performing significantly better. Again, con-
servatism would suggest a longitudinal steel content of perhaps
0.6 percent.

(3) The extent and condition of the longitudinal cracks that developed
in the absence of a center joint leave no doubt as to the need for
a center joints.

(4) The magnitude of the movement that has taken place at unrestrained
section ends suggests that some further study of the control of
slab ends is needed. Whether some form of restraint needs to be
provided, or whether an improved expansion joint that will provide
a positive means of load transfer or of slab support is needed, is
not known.

(5) Some form of subbase to control pumping is suggested.

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TABLE 1

TEST SECTION DETAILS

Section	Length	Thickness	Longitudinal Steel		
			Diameter	Spacing	Percent
	(ft.)	(in.)	(in.)	(in.)	(%)
1	3504	7	3/8	5 1/4	0.3
2	3504	7	1/2	5 9/16	0.5
3	3504	7	5/8	6 1/4	0.7
4	3504	8	3/8	4 9/16	0.3
5	3504	8	1/2	4 13/16	0.5
6	3508	8	5/8	5 7/16	0.7
7	4233	8	3/4	5 7/16	1.0
8	4233	7	3/4	6 1/4	1.0

Note: Transverse reinforcement 3/8-in. diameter round deformed
bars at 12-in. centers in half of each section and at
18-in. centers in other half.

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TABLE 2

RESULTS OF MILL TESTS OF REINFORCING STEEL

Bar No.[1]	No. of Tests	Yield Point (psi)	Tensile Strength (psi)	Elongation (%)
(a) Longitudinal Reinforcement				
3	6	78,701	119,469	14.3
4	14	66,223	107,355	14.5
5	17	70,778	127,759	12.5
6	21	70,157	124,888	11.7
(b) Transverse Reinforcement				
3	7	43,498	77,356	21.5

[1] Normal diameters of 3/8, 1/2, 5/8, 3/4 inches, respectively

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TABLE 3

LONGITUDINAL CRACKING IN TEST SECTIONS

Pavement Thickness (in.)	Section No.	Date Con. structed (inclu- sive)	Longi- tudinal Steel (%)	Percent of Section Length Showing Longitudinal Cracking			
				March 1948	Dec. 1948	Sept. 1957	June 1967
7	1	9/25/47 9/30/47	0.3	0	22	57	77
	2	9/30/47 10/ 3/47	0.5	0	30	81	91
	3	10/ 3/47 10/ 7/47	0.7	0	39	63	76
	8	10/14/47 10/17/47	1.0	44	72	81	92
8	4	4/30/48 5/20/48	0.3	-	0	6	56
	5	4/26/48 4/30/48	0.5	-	0	6	84
	6	11/ 6/47 12/ 3/47 4/22/48 4/26/48	0.7	-	0	13	52
	7	10/14/47 10/17/47	1.0	48	68	76	87

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TABLE 4

ROUGHNESS INDEXES FOR EXPERIMENTAL PAVEMENT
AND ADJOINING CONVENTIONAL PAVEMENT

Test Section	Steel Content (%)	Pavement Thickness (in.)	Roughness Index			
			1957	1962	1964	1967
				(in. per mi.)		
1	0.3	7	73	87	78	92
2	0.5	7	70	81	72	74
3	0.7	7	68	70	79	70
4	0.3	8	71	75	74	78
5	0.5	8	74	79	73	80
6	0.7	8	79	79	76	81
7	1.0	8	71	71	71	70
8	1.0	7	70	70	71	75
Conventional pavement			81	85	78	81

Note: Illinois Adjective Ratings for Roughness of Rigid Pavements

Roughness Index Range	Adjective Rating
Less than 75	Very smooth
75 - 89	Smooth
90 - 124	Slightly rough
125 - 169	Rough
170 - 219	Very rough
220 or more	Unsatisfactory

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TABLE 5

PRESENT SERVICEABILITY PERFORMANCE
OF EXPERIMENTAL PAVEMENT
AND ADJOINING CONVENTIONAL PAVEMENT

Test Section	Steel Content (%)	Pavement Thickness (in.)	Year	Cracking (lin. ft./ 1000 sq. ft.)	Patching (sq. ft./ 1000 sq. ft.)	Roughness Index (in./mi.)	Present Serviceability Index
1	0.3	7	1962	0.3	143.6	87	2.6
			1964	14.3	172.5	78	2.7
			1967	45.4	153.0	92	2.4
2	0.5	7	1962	3.9	50.2	81	3.2
			1964	4.6	50.2	72	3.4
			1967	6.8	50.2	74	3.3
3	0.7	7	1962	0.0	0.0	70	4.0
			1964	0.0	0.0	69	4.2
			1967	3.7	0.0	70	4.0
4	0.3	8	1962	8.6	1.7	75	3.7
			1964	15.1	2.8	74	3.6
			1967	34.0	7.6	78	3.3
5	0.5	8	1962	0.5	0.0	79	3.8
			1964	0.3	0.5	73	4.0
			1967	6.3	0.2	80	3.6
6	0.7	8	1962	0.0	0.0	79	3.9
			1964	0.0	5.8	76	3.8
			1967	1.4	11.9	81	3.5
7	1.0	8	1962	0.0	0.0	71	4.1
			1964	0.0	0.3	71	4.1
			1967	0.4	1.9	70	4.0
8	1.0	7	1962	0.0	0.0	70	4.1
			1964	0.0	0.3	71	4.1
			1967	0.0	1.2	75	3.9
Conventional pavement			1962	0.3	0.0	85	3.7
			1964	3.2	0.1	78	3.8
			1967	4.0	0.2	81	3.7

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TABLE 6

VOLUME AND CHARACTER OF TRAFFIC ON EXPERIMENTAL PAVEMENT AND ADJOINING CONVENTIONAL PAVEMENT

	AVERAGE DAILY TRAFFIC							
	1950	1953	1956	1959	1962	1965	1967
Passenger cars	2,060	3,100	2,885	3,000	3,400	4,500	4,810
Single-unit trucks	305	340	335	390	400	525	702
Multiple-unit trucks	300	760	1,030	1,210	1,100	1,475	1,768
Cumulative 18,000-lb single-axle equivalent loadings	207,000	737,000	1,400,000	2,178,000	2,889,000	3,524,000	4,273,000

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1950   1957

0.3% LONGITUDINAL STEEL

0.5% LONGITUDINAL STEEL

0.7% LONGITUDINAL STEEL

1.0% LONGITUDINAL STEEL

TRANSVERSE CRACKS PER 100 FEET OF PAVEMENT

18 14 10 6 2 2 6 10 14 18

DISTANCE FROM CENTER OF SECTION, 100 FT.
- 7 INCH PAVEMENT

Fig. 1

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7 INCH PAVEMENT

0.3% Steel

0.5% Steel

0.7% Steel

1.0% Steel

AVERAGE CRACK INTERVAL, FEET

AGE OF PAVEMENT, YEARS

Fig. 2

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Fig. 3

8 INCH PAVEMENT

0.3% Steel

0.5% Steel

0.7% Steel

1.0% Steel

AVERAGE CRACK INTERVAL, FEET

AGE OF PAVEMENT, YEARS

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7 INCH PAVEMENT

Values are mostly the average for 60 transverse cracks.

Crack Width - 0.001 Inch

- 0.3% Steel
- 0.5% Steel
- 0.7% Steel
- 1.0% Steel

JULY 28, 1948
SLAB 84°F.

AUG. 21, 1957
SLAB 106°F.

AUG. 25, 1967
SLAB 80°F.

Fig 4

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Fig 5

1950

1957

1967

0.3% Steel   0.5% Steel

Figure 6. Typical transverse cracks
in 7-in. sections.
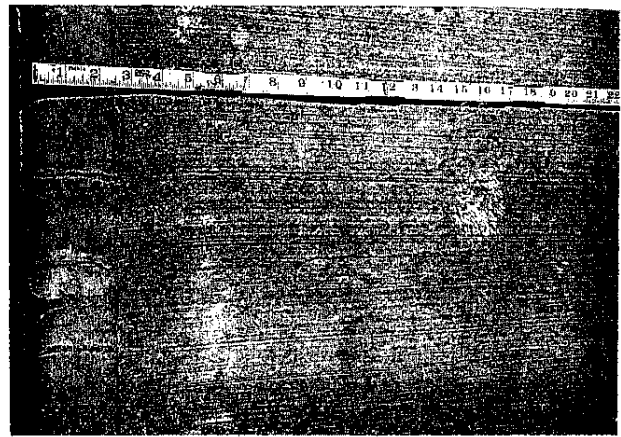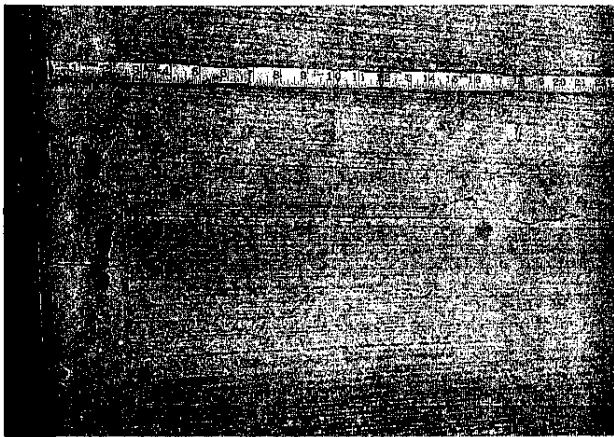
1950
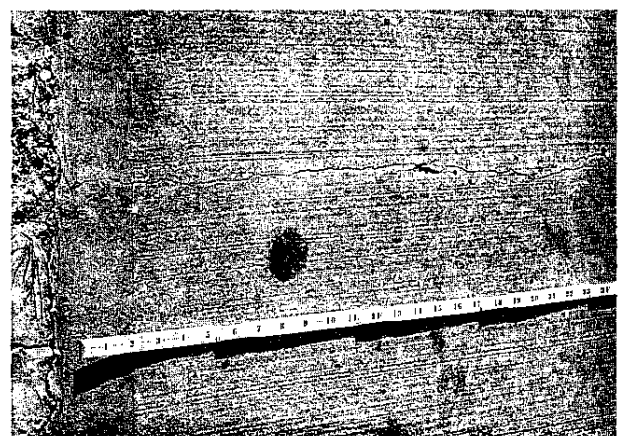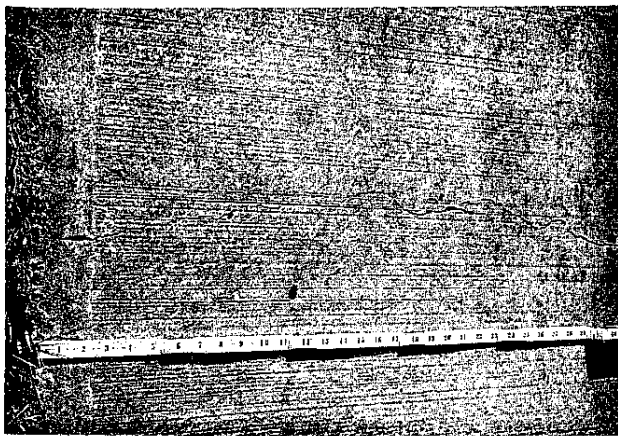
1957
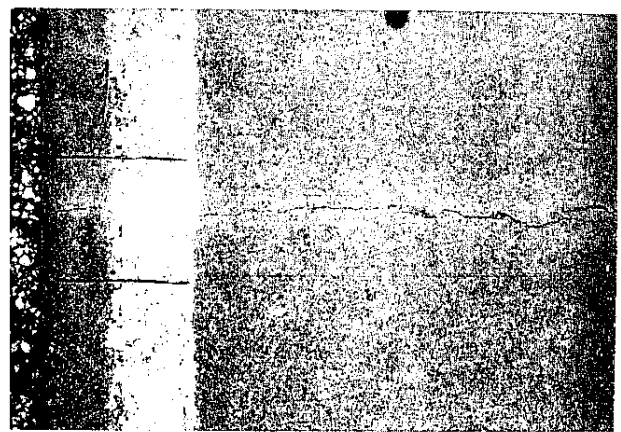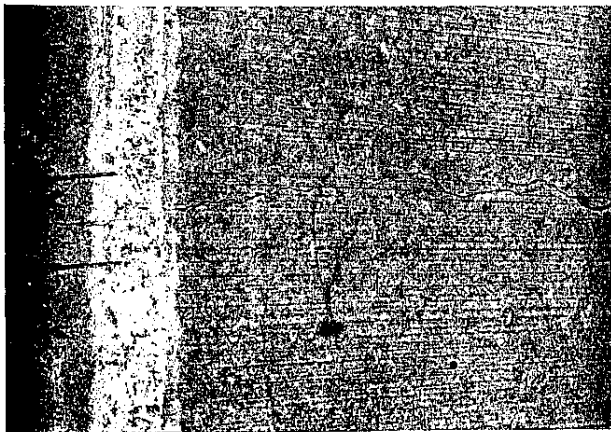
1967

0.7% Steel   1.0% Steel

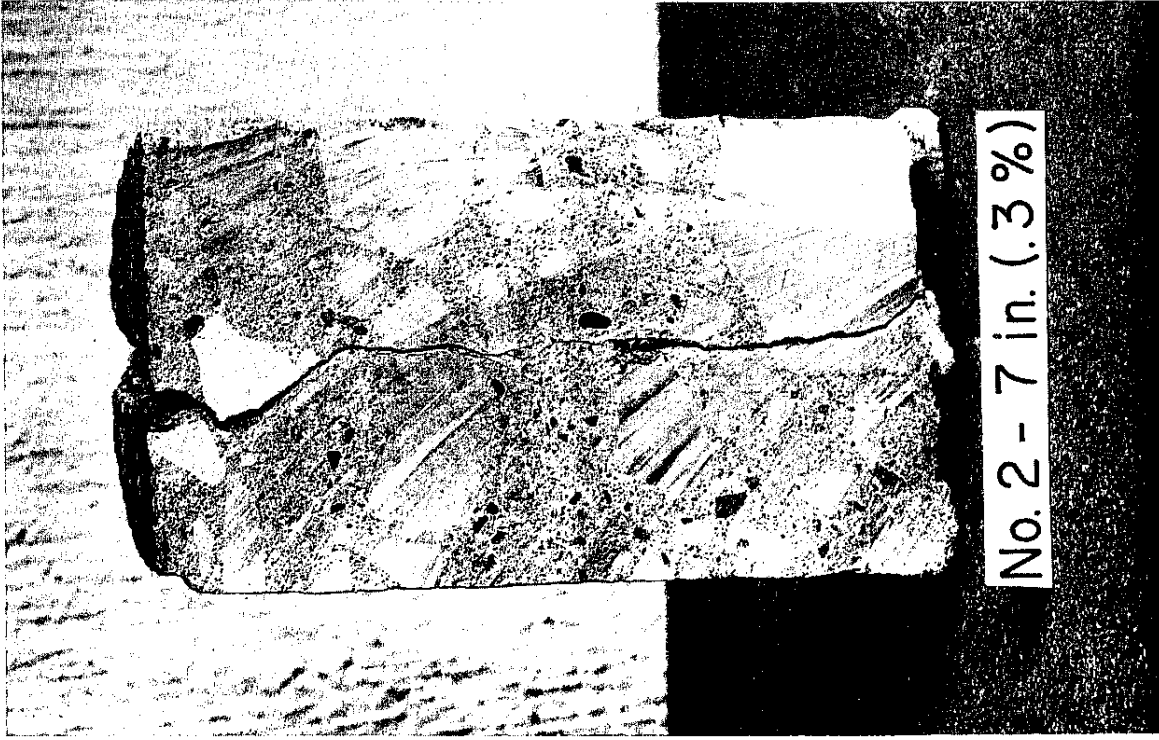Figure 6. Continued

No. 7 - 8 in. (.7%)

No. 2 - 7 in. (.3%)

Figure 7. Condition of transverse cracks as seen in cores sawed to expose clean face of concrete.

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Figure 8. Condition of longitudinal reinforcement bars
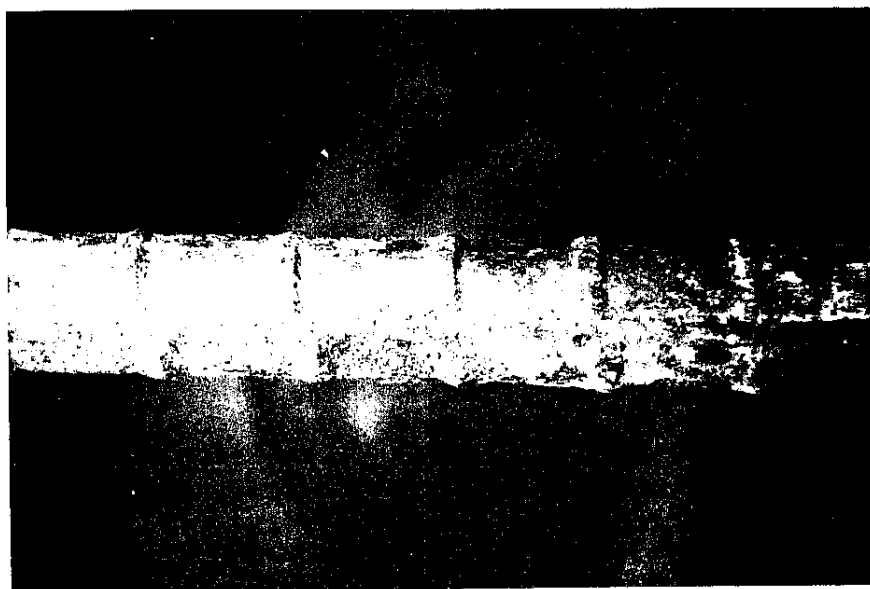in the vicinity of transverse cracks

Figure 9. Condition of longitudinal reinforcement bar
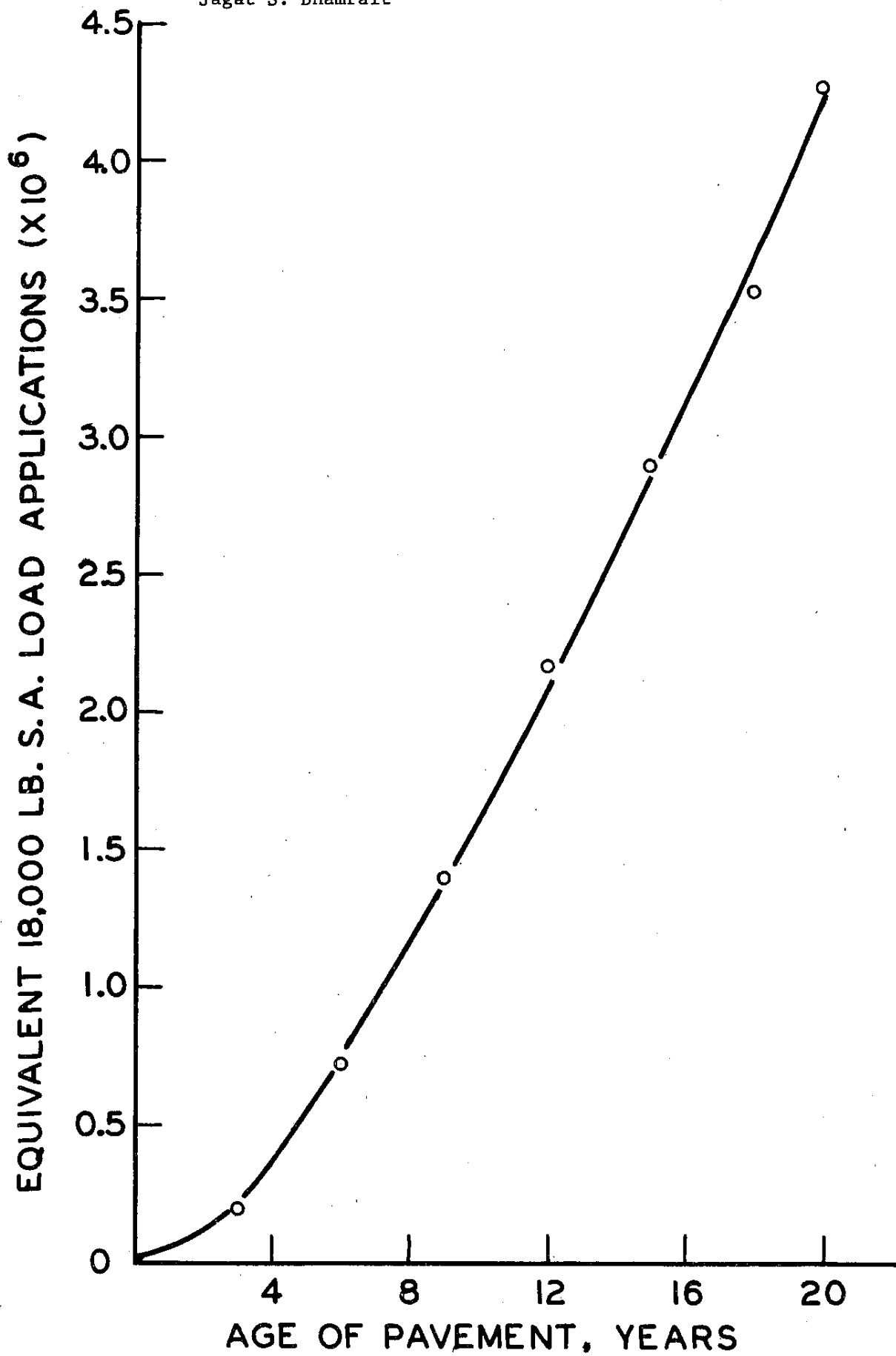in the vicinity of a longitudinal crack

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Fig 10